POWERPLANT STARTING SYSTEM TEST ACTIVITIES

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Abstract

The paper presents the starting system assessment of the T-625 helicopter, a light utility multi-role aircraft designed by the Turkish Aerospace Helicopter Group. T-625 is powered by twin CTS800-4AT turboshaft engines developed by the Light Helicopter Turbine Engine Company (LHTEC). The turboshaft engines are governed by an advanced, redundant dual-channel full authority digital engine control (FADEC) system. Ground and flight tests were conducted to assess the system's reliability, encompassing battery start, cross-engine start, and ground cart start functionalities. Tests were conducted under various weather conditions to ensure robustness. Engine starting system integration to the T-625 helicopter was successfully demonstrated with both ground and flight test campaign considering engine installation and certification requirements. In conclusion, engine starting system is approved by the engine manufacturer.

1. NOTATION

In this paper, abbreviations are used to describe the performance and reliability of different starting systems for a helicopter engine. Below is a list of the key abbreviations, their definitions, and units, where applicable:

Acronyms:	
AGB	Accessory Gear Box
CIT	Compressor Inlet Temperature
ECP	Engine Command Position
ECU	Electronic Control Units
ERF	European Rotorcraft Forum
FADEC	Full Authority Digital Engine Control
GPU	Ground Power Unit
HMU	Hydromechanical Unit
NG	Gas Generator Turbine Speed
NP	Power Turbine Speed
NR	Main Rotor Speed
OAT	Outside Ambient Temperature
PLA	Power Lever Angle
PTIT	Power Turbine Inlet Temperature
S/G	Starter Generator
Vh	Maximum Design Speed

These abbreviations are integral to the analyses presented in this paper, specifically about the testing of starting systems under various operational conditions, both on the ground and in flight.

2. INTRODUCTION

The T-625 Gökbey Helicopter Program, initiated in 2013 by Turkish Aerospace, endeavors to craft a versatile dual-engine helicopter suitable for multi missions such as passenger transport, VIP services, air ambulance, search and rescue, cargo operations, and offshore tasks. The first prototype of the T-625 helicopter performed its maiden flight in September

2018, followed by ongoing certification and qualification flight tests since June 2019. T-625 embodies a 6-ton classhelicopter whose powerplant system features dual LHTEC CTS800-4AT engines, each outfitted with dual-channel FADEC for precise control.

The control of the engines is managed by Full Authority Digital Engine Control (FADEC) units. Each FADEC system comprises two Electronic Control Units (ECU) dedicated to each engine, a hydromechanical Unit (HMU) responsible for fuel pumping and metering, sensors for monitoring aircraft and engine conditions, engine actuators, and wiring harnesses [1]. Figure 1 shows a picture of the CTS800 engine used in T-625.

Figure 1. CTS800 Turboshaft Engine [8]

FADEC manages critical engine parameters such as fuel flow, ignition timing, and overall engine monitoring to ensure optimal performance and efficiency [2, 5]. During the initial engine start process, the required force typically originates from the starter motor, which can be powered by electrical or pneumatic sources. The aircraft's electrical system, auxiliary power unit (APU), or ground power unit can fulfill this mission. Different alternatives have different cons and pros but for T-625's case, an electrically powered starting mechanism was chosen over a pneumatic one. Once the engine reaches a certain speed and ignition occurs, the FADEC takes control, adjusting parameters as necessary to maintain optimal performance throughout various flight conditions. Figure 2 shows a model of a Starter Motor used in T-625.

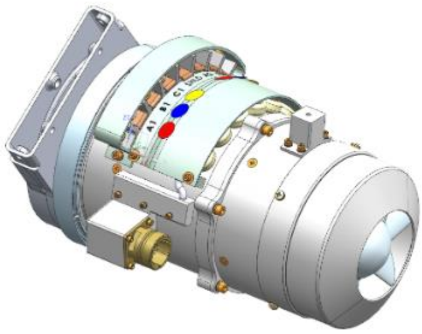

Figure 2. Starter Motor

Starter/generator which is connected to the AGB on engine is used to accelerate the gas generator turbine to a sufficient speed for ignition and to reach a selfsustaining speed during a start. The relay is actuated by the ECU in response to a start request signal from the engine control panel in cockpit. Beside starter function, S/G is used as generator to supply electrical power to helicopter systems after gas generator turbine sufficient speed reached.

Dual TB30 batteries are used in T625 helicopter, which have the following main features [7]:

- Automatic internal heater
- Higher voltage during engine start
- Low weight
- Less wear
- Less maintenance
- Increased life.

In this paper, preparation stages of starting sytem test campaign and the comparison of the starting duration for different conditions are explained.

These preparations involve laboratory tests, engineering simulator runs, ground and flight tests to assess differences in starting methods, as described in the following sections.

3. STARTER GENERATOR LABORATORY TESTS

The turboshaft engine starter generator undergoes rigorous laboratory tests to ensure optimal performance, reliability, and safety in helicopter applications. The starting torque generation test evaluates the S/G unit ability to provide sufficient torque for engine rotation up to self-sufficient speed under varying environmental conditions while the speed regulation test assesses S/G unit capacity to maintain a consistent voltage and current generation during operation. Furthermore, efficiency testing measures the starter generator's ability to convert electrical energy into mechanical energy with minimal loss, ensuring efficient energy transfer during both starting and generating modes of operation. The durability test subject the unit to prolonged operation under simulated operating conditions to evaluate its long-term reliability. Additionally, overload testing evaluates the unit's resilience to sudden increases in electrical load, while environmental testing assesses its performance in varying environmental conditions such as hot and cold weather situations. These comprehensive laboratory tests collectively ensure that the starter generator meets stringent performance standards and can withstand the demanding operational environments of helicopter turboshaft engines, thus enhancing overall system reliability and safety. The laboratory test bench is provided in Figure 3.

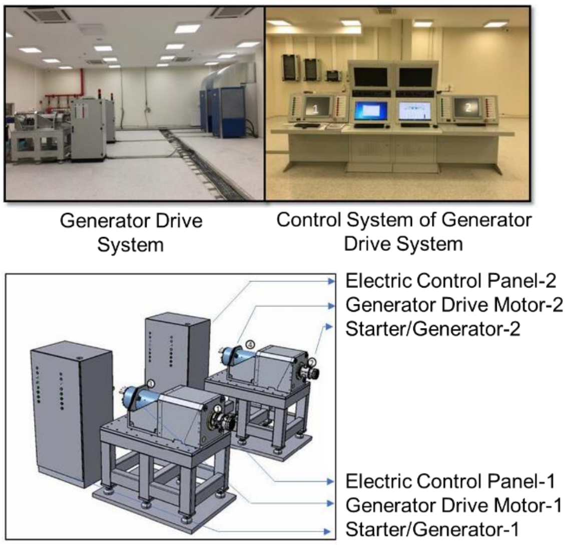

Figure 3. Laboratory Test Bench

In Figure 4 and Figure 5, the torque curves of the Starter Generator are given for different values of volts, and amperes, and the minimum torque requirements to overcome the inertia of CTS800 at different temperatures are given. The V and OAT values given in the legends of Figure 4 and Figure 5 represent the voltage values and temperatures respectively. As the values proceed from V1 to V6, the voltage supplied to the S/G increases. This increase causes the torque output given to the engine to increase. Likewise, the outside ambient temperature increases from OAT1 to OAT3, indicating that the torque required to start the engine in cold conditions increases.

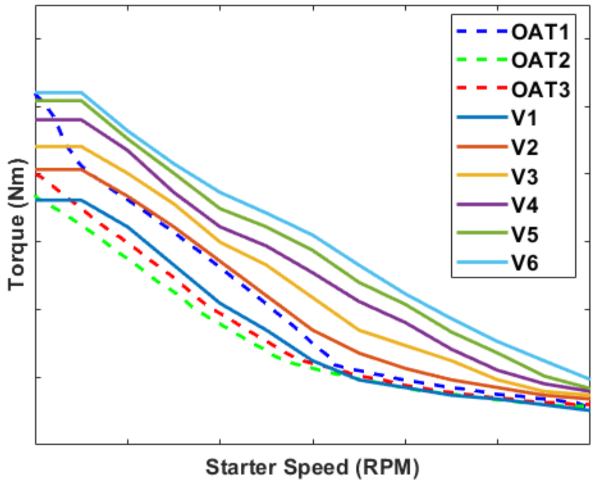

Figure 4. Minimum Starter Torque Requirement & Starter Generator Torques for Different Temperature and Voltage Values for Low Amper

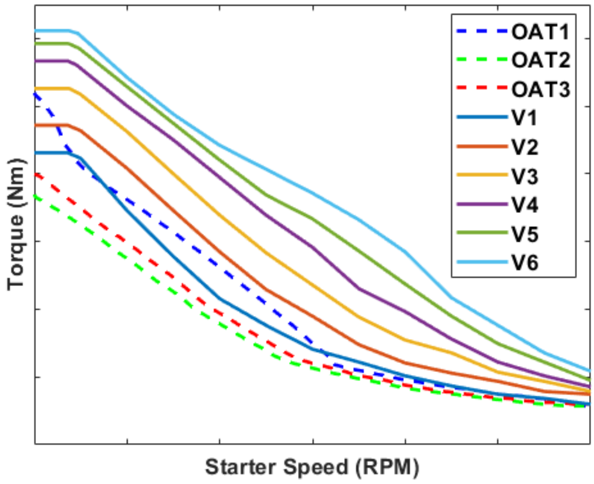

Figure 5. CTS800-4AT Minimum Starter Torque & Starter Generator Torque for Different Temperature and Voltage Values for High Amper

4. ENGINEERING SIMULATOR

The T-625 helicopter program prioritized the development of a robust simulator environment, initially as a System Integration Laboratory (SIL) for hardware-in-the-loop tests, particularly focusing on refining the automatic flight control system (AFCS). As the program progressed, the SIL transitioned into a sophisticated pilot-in-the-loop preparation facility, offering realistic training scenarios for the flight test crew. Equipped with a fixed-based simulator featuring replicated glass cockpit displays, including screen-integrated modular displays (IMDs) and cockpit control Units (TCCUs), The simulator provided a wide field of view for pilot visualization during maneuvers [4, 6].

Figure 6. T-625 Engineering Simulator

T-625 simulator as shown in Figure 6 for pilot in the loop and hardware in the loop simulations. Additionally, the simulator faithfully replicated conventional flight control systems, including cyclic, collective, and pedals, interconnected to trim actuators with robust mechanical linkages, ensuring pilots experienced realistic flight conditions. Avionics equipment such as real flight control computers (FCCs) and mission-critical panels like the engine control panel (ECP) and fuel system control panel further enhanced training scenarios.
Simulator tests proved invaluable in preparing flight crew for upcoming flight tests and providing insights to the engineering team. By analyzing simulator flight data, shortcomings in flight test techniques or data reduction methods could be promptly addressed, leading to continued refinement and improvement before real test flights. The simulator also facilitated pilot-in-the-loop simulations, allowing crews to anticipate helicopter and powerplant characteristics before actual flight tests, particularly during engine shutdown and starting tests. This individual test scenario estimated the engine controller's initial performance validating and refining the system functionality before real-world flight testing.

The simulator has been actively used to enhance the pilot's awareness of possible helicopter behaviors during engine shutdown and engine restart tests at different altitudes and speeds.

5. GROUND TESTS

Before conducting engine starting system tests in flight, it was crucial to perform comprehensive ground tests on the prototypes. These ground tests ensure the reliability and functionality of the starting system under various conditions. These procedures involved checking the integrity of all electrical connections, verifying the functionality of individual components such as the starter motor, ignition and fuel system, and assessing the responsiveness of the engine control system. Additionally, ground tests allowed for the calibration of sensors and instruments, including the identification and adjustment of any potential issues before flight testing.

The ground-based tests were designed to prove the reliability of various engine starting methods, including battery, ground cart, and cross engine start. These methods can be explained as follows;

1. **Battery Start:** Uses the helicopter's own battery to power the engine start.
2. **Ground Cart Start:** Utilizes an external electrical power to start the engine.
3. **Cross-Engine Start:** Uses the power from the first engine to start the second by supplying power to the battery.

As shown in Figure 7, Figure 8, and Figure 9, engine parameters varied depending on the method used and the environmental conditions. Following these tests, the results proved to be consistent with those obtained from laboratory tests, validating the reliability of the starting methods in various scenarios.

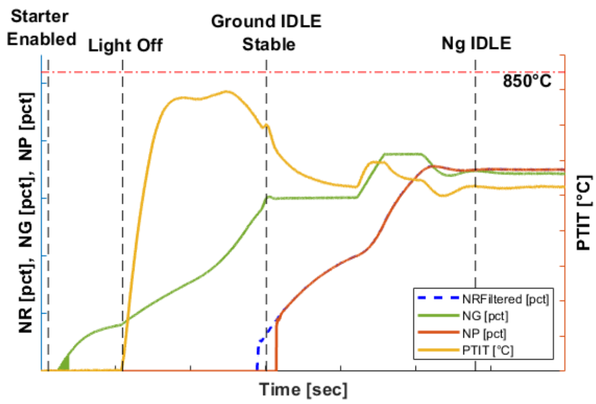

Figure 7. Example of Engine Starting Test with Battery

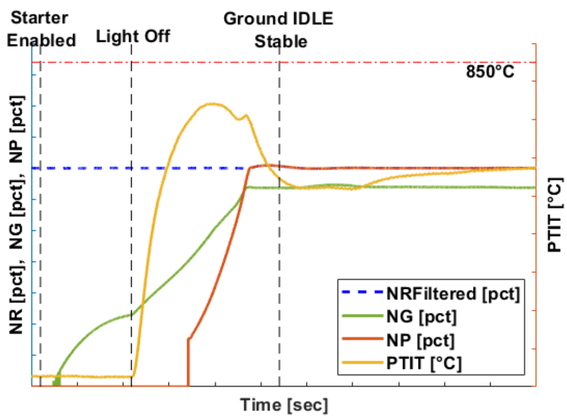

Figure 8. Example of Cross Engine Start

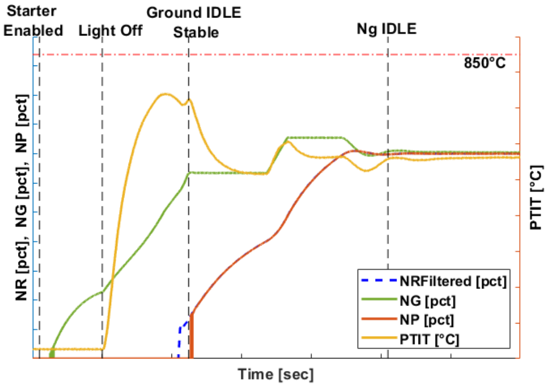

Figure 9. Example of Engine Starting with GPU

The starting process of the engine and helicopter starts by switching the PLA from the OFF position to the IDLE position. In this step, the signals required to start the engine are sent to the S/G and FADEC. This signal converts the electrical energy coming from the battery or GPU into mechanical energy through the S/G and the gas generator of the engine starts to rotate with the engine-mounted gearbox which is also connected to S/G. When the inducted air by the rotating compressor reaches a sufficient mass flow level, the ignition system and fuel system are activated. Then, the NR rotating with the output of the turboshaft starts to accelerate and remains fixed in the IDLE position. It should be noted that the flow created while NG is rotating causes the rotation of the power turbine and naturally the rotation of the main rotor. However, this rotation is small enough to be compared to the rotation that will occur while light off is initiated.

There are several critical criteria to ensure the reliable operation of the helicopter engine starter system. These criteria are important not only for safe engine operation but also to prevent long-term damage and performance degradation. To verify the reliability of the starter system and engine, the following conditions must be met:

• NG should reach a specific percentage within a designated time frame.

• PTIT should not exceed 850°C (1,562°F) [3].

• NG should keep increasing above self-sustained rpm.

• Unusual noise or vibration should not occur (Evaluation according to pilot's feedback).

• ECU Failure should not occur.

• The engine should light off within a designated time frame (when the Engine Starting on the Ground).

• The engine should light off within a designated time frame (when the Engine Re-Starting in the Air).

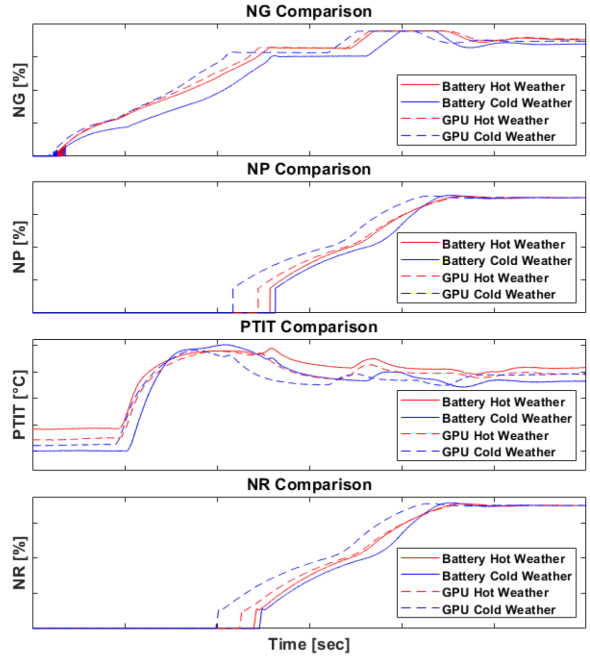

Figure 10. Comparison of Engine Parameters under Cold and Hot Weather Conditions Using Battery and GPU

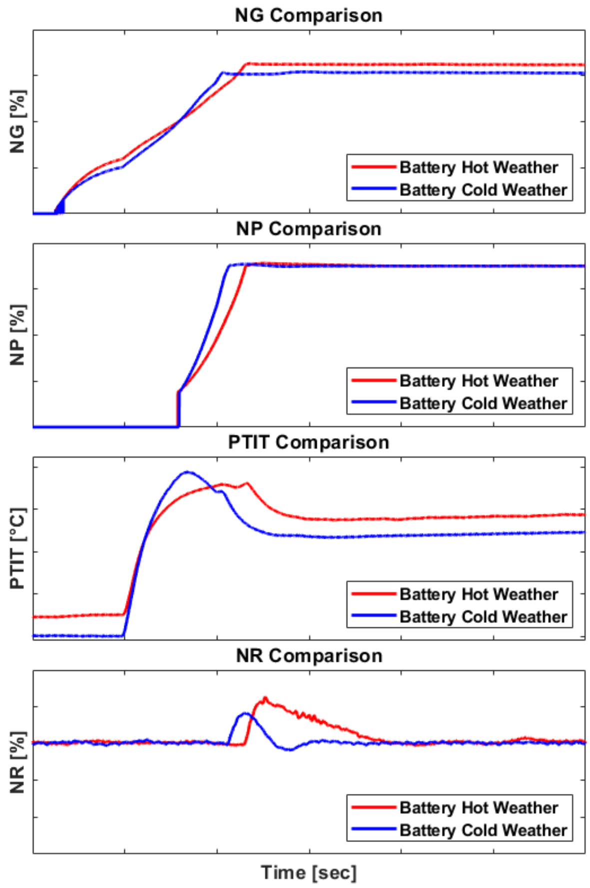

Figure 11. Cross Start in Hot and Cold Weather

The battery, ground cart, and cross-start method have been used to examine the behavior of the engine starting in hot and cold weather. This comparison is provided in Figure 10 and Figure 11. The important point in this comparison is that as the air cools, its density increases, and the fuel entering the combustion chamber can burn more efficiently with the denser air. With this interpretation, it can be observed that NP has a higher increase rate in cold weather compared to NP in hot weather scenarios. In addtion, the higher increase rate causes maximum power turbine inlet temperature reached during the start higher than hot weather. Nevertheless, the maximum PTIT in all cases is below the starting criterion (850°C).

Besides, as far as it can be seen in Figure 10, the NG acceleration rate in GPU start is higher than the battery's because the power (voltage and current) of the GPU is slightly higher than the battery's.

6. FLIGHT TESTS

After the successful completion of the ground testing and the valuable insights gained from simulator simulations, the next phase involves the meticulous planning and execution of flight tests. These flight tests serve as a crucial step in validating the performance of the T-625 helicopter and its engine in real flying conditions.

These inflight tests are similar to the cross-start method performed on the ground. This is because it uses the power generated from the engine in operation to start the engine that is not running. However, the key distinction between these two test points is the position of the PLA: in air-restart tests, the PLA is set to FLIGHT rather than IDLE. As illustrated in Figure 12, the PLA reaches FLIGHT mode whereas in Figure 8, the PLA is pulled back to IDLE.

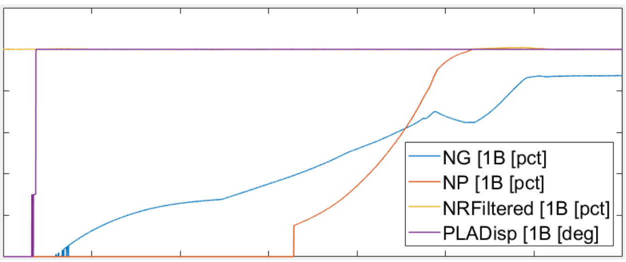

Figure 12. Engine Air-restart at high altitude, 1.0 VH

In flight tests, the necessary conditions for engine restart tests, as per the requirements of the engine company (LHTEC), are as follows.

Table 1. In-flight Restart Test Conditions

Altitude [ft]	Airspeed [knots]
Low altitude	0.3 Vh
Low altitude	0.6 Vh
Low altitude	1.0 Vh
Mid altitude	0.3 Vh
Mid altitude	0.6 Vh
Mid altitude	1.0 Vh
High altitude	0.3 Vh
High altitude	0.6 Vh
High altitude	1.0 Vh

These tests were successfully performed for each engine without any problems. The engine restart times are shown in Figure 13. In this figure, the time between minimum restart time and maximum restart time is less than 2.5 seconds and no significant correlation was found between the data. This is due to the outside ambient temperature difference between the tests performed. Complex and multiple factors like these may prevent a clear correlation between engine restart times.

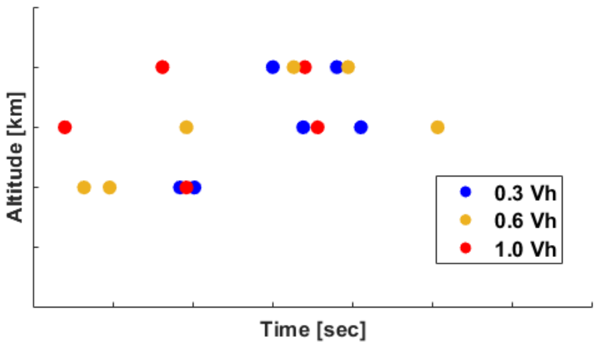

Figure 13. Engine Restart Times

7. CONCLUSION

Throughout ground and flight test campaign, engine starting tests were conducted to assess the reliability of the starting system and to determine the factors affecting the runtime. The tests were conducted with a special focus on evaluating the starting characteristics of the engine and improving the helicopter's smooth engine start-up capabilities.

At the current stage of the T-625 helicopter program, starting system tests have been successfully conducted by late 2023 and early 2024, coinciding with winter weather conditions contributing to cold weather testing.

Based on laboratory and test results, some information and limitations were defined to rotocraft flight manual in order to increase pilot awareness and system reliability.

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